Illumination: transport of energy from light sources to surfaces and points via direct & indirect paths.

Lighting: computing intensity reflected from 3D point in scene.

Shading: assigning pixel colours

Illumination Models:

- Empirical: simple approximations to observed phenomena.
- Physically-based: model actual physics of light interactions.

Angular Attenuation:

$$f_{l,angatten} = \begin{cases} 1.0, & \text{if source is not a spotlight} \\ 0.0, & \text{if } \mathbf{V}_{\mathbf{obj}} \cdot \mathbf{V}_{\mathbf{light}} = \cos\alpha < \cos\theta_l \\ & \text{(object is outside the spotlight cone)} \\ (\mathbf{V}_{\mathbf{obj}} \cdot \mathbf{V}_{\mathbf{light}})^{a_l}, & \text{otherwise} \end{cases}$$

Lighting Model:

- *Diffuse* component for the amount of incoming light reflected equally in all directions

$$I_{l,diff} = k_d I_{l,incident} = k_d I_l \cos\theta$$

- *Specular* component for the amount of light reflected in a mirror-like fashion

$$I_{l,spec} = \begin{cases} k_s I_l (\mathbf{V} \cdot \mathbf{R})^{n_s}, & \text{if } \mathbf{V} \cdot \mathbf{R} > 0 \text{ and } \mathbf{N} \cdot \mathbf{L} > 0 \\ 0.0, & \text{if } \mathbf{V} \cdot \mathbf{R} < 0 \text{ and } \mathbf{N} \cdot \mathbf{L} \le 0 \end{cases}$$

- Specular reflection is both dependent on the light direction, surface orientation, and ***viewer position***

  - *Ambient* term to approximate light arriving via other surfaces

$$k_a I_a$$

Ideal diffuse reflector : *Lambertian* reflector

You can combine ambient and diffuse as the following equation

$$I_{l,diff} = \begin{cases} k_a I_a + k_d I_l (\mathbf{N} \cdot \mathbf{L}), & \text{if } \mathbf{N} \cdot \mathbf{L} > 0 \\ k_a I_a, & \text{if } \mathbf{N} \cdot \mathbf{L} \le 0 \end{cases}$$

$$\mathbf{L} = \frac{\mathbf{P}_{source} - \mathbf{P}_{surface}}{\left| \mathbf{P}_{source} - \mathbf{P}_{surface} \right|}$$

Ideal Specular Reflector: **R = 2(L.N)N - L**

Using these coefficients and Fresnel's Laws of Reflection we can write the Phong specular reflection model as

$$I_{spec} = W(\theta) I_l \cos^{n_s} \phi$$

most common lighting model in computer graphics:

$$I_{specular} = k_s I_{light} \cos^{n_{shiny}} \phi$$

Specular Reflection Speedup:

- Specular Reflection (Phong Model):

$$I_{specular} = k_s \, I_{light} \, (V.R)^{shiny}$$

- Modified Phong Model:

$$I_{specular} = k_s \, I_{light} \, (N.H)^{shiny}$$

You can combine ambient and specular as the following equation

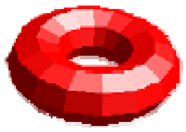
$$\begin{aligned} I &= I_{diff} + I_{spec} \\ &= k_a I_a + k_d I_l (\mathbf{N} \cdot \mathbf{L}) + k_s I_l (\mathbf{N} \cdot \mathbf{H})^{n_s} \end{aligned}$$

Multiple light sources:

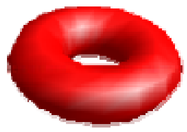
$$I = k_a I_a + \sum_{i=1}^{n} I_{l_i} [k_d (\mathbf{N} \cdot \mathbf{L}_i) + k_s (\mathbf{N} \cdot \mathbf{H}_i)^{n_s}]$$

Polygon Rendering Methods

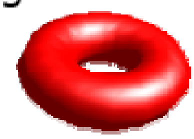
- Constant intensity rendering:
  - No interpolation.
  - Also called "flat shading"



- Intensity interpolation rendering:
  - "Gouraud shading"
  - Based on intensity interpolation of vertices.



- Normal vector interpolation rendering:
  - "Phong shading"
  - Based on interpolation of normal vectors of vertices.



Flat Shading:

- Advantages:
  - Fast - one shading value per polygon
  - Works well for objects

    really made of flat faces (polyhedron).
- Disadvantages:
  - Inaccurate
  - Discontinuities at polygon boundaries

Gouraud Shading:

- Advantages:
  - Fast - incremental calculations when rasterizing
  - Much smoother - use one normal per shared vertex to get continuity between faces
- Disadvantages:
  - Specularities get lost

Phong Interpolation:

- Advantages:
  - High quality, narrow specularities
- Disadvantages:
  - Expensive
  - Still an approximation for most surfaces